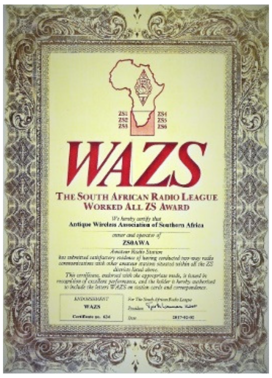
Antique Wireless Association of Southern Africa Newsletter

 # 194 **Sept 2022**



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Reflections:

Never in my life did I ever think that I would find enjoyment in playing with radio's.

From a very young age we always had music playing in our house, thanks to my mother and Phillips .

We had a Phillips radio gram that stood in the one corner in our lounge that had one of the roll up doors on the top that revealed the gramophone and there would more often than not be a record playing on it. More than likely Mantovani or some big band music.

If no record was on then it would be tuned to BBC via a spider type antenna that my brother had made and stuck up on the rain gutter outside the lounge.

That was my closest encounter with radio at a young age.

Not even while growing up and travelling to boarding school or thereafter was there ever an introduction to electronics or radio. It was very late in life, only after I was married, that I heard about CB radio and bought one to be able to chat with the "maatjies" while living in the Northern Cape.

Of course there was all the illegal extra's that eventually went with it including a home brew 2 element yagi that enabled all the DX that we could handle.

Of course in those days the bands were so good that the proverbial wet shoestring could have done as well.

It was because of having at least some kind of radio interest that I ended up being drawn into Comms in the military side and meeting my mentor who was the head of comms, but also a radio ham.

Since then, I never looked back and have had radio infused into my system, that it is almost something that has become like a drug. If I don't get my daily dose of RF, then something is definitely wrong and strange things start to happen. I'm sure there may be some who can identify with these symptoms.

I often listen to others speaking about how they were introduced to radio/ electronics from a very young age and wonder if I would have been any different in my outlook today ? Quite honestly, I don't think so.

I may have been able to not say "that's beyond my pay grade", but I think I would have got as excited about radio as I still do. The thing that excites me about opening up a radio is all those tubes and capacitors and things. It's like a thick juicy steak with fat around the edge. I can't feel the same way looking at surface mount stuff.

What is it that drew so many of you in to amateur radio ? Are you still as excited about it as you were the day you got your license ?

Give me something to publish in our next issue.

Best 73

DE Andy ZS6ADY

Wikipedia

Solar Flares:

Frequency

The frequency of occurrence of solar flares varies with the 11-year solar cycle. It can range from several per day during solar maximum to less than one every week during solar minimum. Additionally, more powerful flares are less frequent than weaker ones. For example, X10-class (severe) flares occur on average about eight times per cycle, whereas M1-class (minor) flares occur on average about 2000 times per cycle.

Erich Rieger discovered with co-workers in 1984 an approximately 154 day period in the occurrence of gamma-ray emitting solar flares at least since the solar cycle 19. The period has since been confirmed in most heliophysics data and the interplanetary magnetic field and is commonly known as the *Rieger period*. The period's resonance harmonics also have been reported from most data types in the heliosphere.

Duration

The duration of a solar flare depends heavily on the wavelength of the electromagnetic radiation used in its calculation. This is due to different wavelengths being emitted through different processes and at different heights in the Sun's atmosphere.

A common measure of flare duration is the full width at half maximum (FWHM) time of soft X-ray flux within the wavelength bands 0.05 to 0.4 and 0.1 to 0.8 nanometres (0.5 to 4 and 1 to 8 ångströms) measured by the GOES spacecraft in geosynchronous orbit. The FWHM time spans from when a flare's flux first reaches halfway between its maximum flux and the background flux and when it again reaches this value as the flare decays. Using this measure, the duration of a flare ranges from approximately tens of seconds to several hours with a median duration of approximately 6 and 11 minutes in the 0.05 to 0.4 and 0.1 to 0.8 nanometre bands, respectively.[8][9]

Solar flares lasting longer than approximately 30 minutes are regarded as long duration events

CRYSTAL OSCILLATORS

After publishing the article from Wikipedia in the August 2022 edition, I received an email from John ZS5JF which is correctional in many ways and this article is published with his permission….

Unfortunately some of the information about xtal oscillators is not strictly correct. Having spent a large part of my professional career designing xtal oscillators I have become wary of some of the published facts on sites like wikipedia! I have trusted the suppliers technical data from companies such as KVG, SEI and NDK etc and found they all give the same information.

Xtals are predominately series resonant circuits but the common usage of 'parallel resonant' is not in fact true. The preferred name is 'fundamental oscillators'. The existence of the so-called 'parallel resonance' is a quirk when the xtal is presented with an excitation voltage which is above the true series resonant mode.

Manufacturers of xtals can grind the xtal blank to move the series resonant frequency but have little control over the parallel resonant frequency. For xtals intended for use on the 'parallel resonant frequency' it requires a specific shunt (parallel) connected capacitor. This is usually a value of about 30pF for most xtals. As the xtal behaves like a very high Q inductor when excited at a frequency above the series resonant mode the actual oscillation frequency is dependant on the value of the shunt capacitance across the xtal. This allows some slight adjustment of the oscillation frequency. However, the 'activity' of the xtal has a large part in whether the amplifier stage gain needs to be higher or lower to ensure reliable starting and stable oscillation. Too much gain can make the xtal oscillator jump from the parallel to the series mode. This is especially important for overtone oscillators as the wrong amount of feedback can make the xtal oscillate on either the fundamental of some other overtone. Note that overtone xtals can never be "even tones" but only "odd tones", so a 10 MHz series xtal can be made to oscillate on 10 MHz (fundamental) or 30 MHz or 50 MHz, 70 MHz etc but not 20 MHz, 40 MHz etc.

If a xtal is measured using an impedance analyser, such as a Vector Network Analyser etc, you will find two specific frequencies very close together, one where it exhibits a very low series resistance (the series mode) where the ESR is approaching zero ohms, and the other, situated a very small frequency higher, shows the xtal is approaching infinite resistance. This second frequency is the so-called 'parallel resonant' mode. The trick is to suppress the series mode and enhance the parallel mode to get reliable oscillation, low spurious oscillations and reliable starting. For xtals intended for 'overtone operation' the value of the ESR is critical to get reliable operation. When designing series resonant oscillators the best method is the substitute the xtal with a resistor of the maximum specified resistance for the xtal type. The oscillator tank circuit is then adjusted to the nominal xtal frequency. In this mode it is simply a VFO circuit. Removing the resistor and putting the xtal in circuit it should then run at the xtal frequency. Some small adjustment can be made by adjusting either the L or C value in the tank circuit to move the xtal to the correct frequency, but this adjustment range is very small. It is important to suppress any tendency to jump from series to parallel mode. This is normally corrected by connecting a low value resistance in shunt with the xtal. A good rule of thumb is to select a value with a value of ten-times the maximum ESR. This means the xtal can never approach the infinite resistance mode if the oscillator is detuned. A good starting point is a 680-ohm resistor.

Similarly with a 'parallel resonant' oscillator a different method can be used. The xtal is substituted with a LC parallel tuned circuit with one element being adjustable in value (usually the C portion but an adjustable L can also be used with a suitable fixed value for C) and the oscillator is adjusted to give approximately the correct frequency. Thereafter the xtal is inserted, having removed the LC network, and the oscillator should run at the xtal frequency. Again some small adjustment is possible by a variable trimmer capacitor or a variable inductor to move the xtal onto the correct frequency.

Note in the 'parallel mode' the capacitance value specified to give the correct nominal frequency is the net shunt capacitance which exists across the xtal. In most low frequency Colpitts oscillators the feedback capacitors are much greater than the nominal shunt capacitance and in this case another series capacitor is required between the oscillator tank circuit and the xtal to allow a trimmer capacitor to be added for the final frequency adjustment. If the Colpitts oscillator requires two 220pF fedback capacitors (one from base to emitter and one from emitter to base) this gives a shunt value of 110pF as there are connected in series and the xtal connected between base and ground will be loaded with 110pF and not the required 30pF. The extra series capacitor between the base and the xtal can be about 33pF allowing a 20pF maximum trimmer to be used. Alternatively the extra capacitor can be placed in the ground lead of the xtal instead of between the base and the xtal, it makes no difference to the operation as long as the value is correct.

All of this is learned the hard way!

Designing Colpitts oscillators

John Fielding ZS5JF

The Colpitts oscillator is one of the classic RF oscillators used widely to generate stable signals for either a fixed frequency application or a variable frequency application. There have been several variations on the basic theme over the years, including the Vackar oscillator, but they all use the same basic concept.

The Colpitts oscillator was invented in the heydays of vacuum tubes and later semiconductor versions used the same basic principles. Unlike types such as the Hartley oscillator the Colpitts is simpler to analyse and design as the feedback mechanism is performed by a capacitor tapped network. In the Hartley and similar designs the feedback is by varying the turns ratio between two series connected inductors and varying the feedback ratio is more difficult and less easy to analyse before the construction begins.

RF oscillators are characterised by several parameters that are important to the application. These include frequency stability, output level, frequency and tuning range and close in phase noise. Not all of these can be optimised together unless great care is taken to attain the best compromise and usually some tradeoffs need to be made.

Where the greatest frequency stability and lowest close in phase noise is essential then the classic LC oscillator is not as good as a crystal controlled type, as crystals can offer loaded Q values well in excess of the best LC oscillators. The highest Q a practical inductor can have is around 600 whereas a crystal Q figure is normally at least 10,000. However, crystal oscillators are essentially "*fixed frequency*" types as the average crystal is made for a specific frequency and it cannot be varied more than a very small amount.

A schematic of a typical Colpitts oscillator is shown in Figure 1 where the basic components are shown. One of the additional parts is the biasing that is often omitted for clarity.

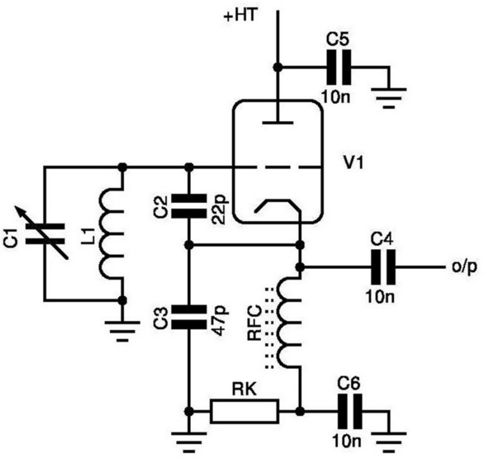

Figure 1 Typical Colpitts oscillator using a vacuum tube

The basic Colpitts oscillator uses two series connected tapped capacitors to produce the feedback signal between the cathode and the control grid. Figure 1 shows a simple triode circuit but it can also use a tetrode or pentode. In these types an additional supply is required for the screen grid pin (g2). The basic building block for the Colpitts circuit is the classic *Cathode Follower*. This is shown in Figure 2.

The cathode follower is a simple amplifier which has zero phase shift between the input and output. The input resistance is very high but the output resistance is low. This makes it the ideal "*buffer amplifier*" where low impedance loads need to be driven from a high impedance source. The voltage gain of a cathode follower is slightly less than 1. In practice it is between 0.95 to 0.99 depending on the frequency of operation. By selection of a suitable tube the gain is almost 1 and the small difference can be ignored in most applications.

Although the voltage gain is only 1 it has a high current gain and it can produce considerable "*power gain*" allowing it to drive low impedance loads with fairly high current.

> The classic tubes used for RF oscillators are the 6C4 and the 12AT7. The 6C4 is a single triode and the 12AT7 is a dual triode. Both have an acceptable "*amplification factor*" commonly known as the mu (ʃ). The 6C4 is typically 20 and the 12AT7 is 60, so it is a better choice. Either one will oscillate up to several hundred MHz in a suitable circuit and draw little current, providing a few volts rms output. There are many other suitable tubes that can be used.

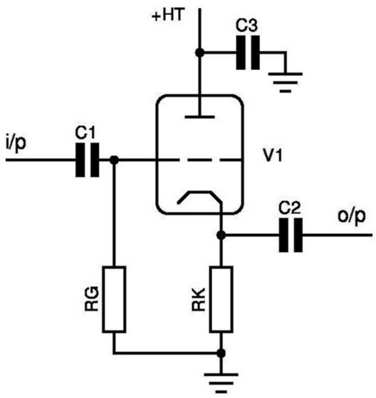

Figure 2 Cathode Follower

In all oscillators a small portion of the output power generated is used to drive the input terminal and if the "*loop gain*" is high enough it is self sustaining once it begins to oscillate. The initial signal is produced from the inherent noise present and this is fed back to the input amplifying the noise. Very quickly the amplitude builds up to a maximum level. The oscillator is inherently "*self limiting*" above a certain output level as the gain falls as the input level is increased. This limiting action in a tube oscillator is caused by the grid current flowing developing a negative bias on the control grid. As the control grid is driven more negative the anode current begins to fall, so lowering the gain of the tube. It settles into a steady state after a few cycles and thereafter it can only change if the external load is varied or the supply voltage changes.

Hence, all oscillators need to drive a fairly constant load to ensure a constant output voltage is attained and a well regulated anode supply voltage if good frequency stability is essential.

The frequency the oscillator will run at is determined by the LC “*tank circuit*” connected in the feedback path. If the tank circuit presents a pure resistance to the input of the oscillator then the phase shift across the feedback path is 0°. Since the cathode follower also has a 0° phase shift from its input to output the tank circuit required is a parallel resonant LC network. This is shown in Figure 3.

> The criteria for oscillation is that the feedback signal through the resonant network must be in-phase and greater than a gain of 1 in voltage terms. A parallel

At resonance a parallel resonant network appears as a pure resistance of a high value, commonly known as the “*Dynamic Resistance*” or RD. The value of RD can be several tens of thousand ohms with good Q components. If the network is resonant then the voltage and current are in-phase and complies with the needed 0° phase criteria at that particular frequency. If the network is tuned to a different resonant frequency then the oscillator will run at the new frequency.

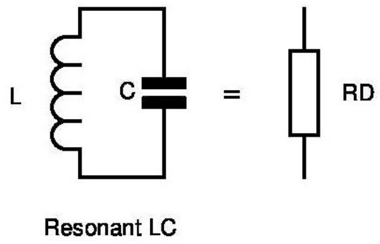

Figure 3 Parallel resonant network and its equivalent circuit

The resonant frequency is determined by the reactance values of L and C. To be truly resonant they must be the same value. Changing the frequency can be achieved by altering either the L or C value to select the required frequency. It is normally easier to change the value of C rather than L, but some oscillators use either or both to get the correct frequency. Variable tuning capacitors are a simple method of varying the resonant frequency, but some oscillators use variable inductors, known as “*Permeability Tuning*” with fixed value capacitors.

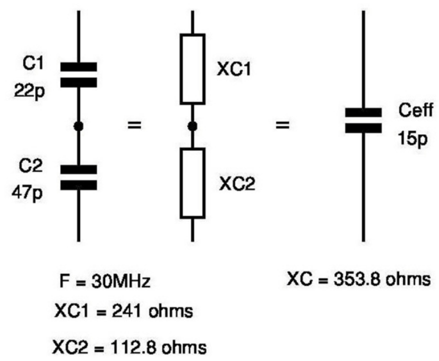

Figure 4 Tapped capacitor voltage divider network

Feedback network

The Colpitts oscillator uses two series connected capacitors between the cathode (output) and the grid (input) as a *constant ratio divider* network. This is shown in Figure 4. Effectively it is a fixed ratio “*step-up*” network. Electrically it behaves the same as a tapped inductance where the drive input is fed in low down on the “*auto-transformer*” winding.

Each capacitor exhibits a reactance determined by its value and the frequency. The ratio between the two reactance’s is constant no matter what the frequency is. In some versions of the Colpitts oscillator the two divider capacitors are the same value giving a 2:1 ratio, but in high input resistance amplifiers such as tubes or FETs, it is usually a larger value at the bottom and a smaller value at the top, giving a higher step-up ratio. High value capacitors have a lower reactance than low value capacitors.

For the example oscillator we have selected a frequency range of 30MHz to 50MHz. Capacitors in series have a total capacitance less than the smallest value. They behave the same way as resistors in parallel. In this example the values are 22pF and 47pF and the reactance in circuit across the inductor is the sum of the two in series. Effectively the 22pF and 47pF connected in series add ≈15pF across the inductor.

Resonance Criteria

To attain a particular frequency of oscillation the reactance of the inductor X_L and the total capacitive reactance X_C across the inductor have to be numerically equal. Inductive reactance rises with increasing frequency whereas capacitive reactance decreases with increasing frequency. The formula for each are:

$$X_L = \omega L \text{ and } X_C = 1 / \omega C \text{ Where } \omega = 2\pi f$$

A 100pF capacitor at 1MHz has a reactance of 1951Ω. The corresponding inductor to resonate at 1MHz is 253⌠H.

At 2MHz a 100pF capacitor has X_C = 795.5Ω and the inductor requires a reactance of the same value and it is 1/4 of the value at 1MHz, being 63.25⌠H.

The choice of main tuning capacitor is often limited to standard air variable capacitors available. In this example we have selected an air variable with a minimum value of 20pF and a maximum of 100pF, a swing of 80pF nominal.

In addition to the tapped capacitor network and the tuning capacitor we have to take into consideration any other capacitance effectively across the inductor. One of these is the grid-cathode capacitance of the tube chosen. In most cases with small tubes it is a fairly low value of 4pF typically.

Hence the total capacitance across the inductor is (15 + 100 + 4) = 119pF when the capacitor is at maximum, with fully meshed plates. At fully unmeshed condition the total capacitance across the inductor is (15 + 20 + 4) = 39pF. These two values determine the minimum and maximum frequency possible with a particular inductor value, and hence the tuning range possible.
We will choose to cover 30MHz to 50MHz and calculate the inductor value required. At the highest frequency the inductor reactance must be the same as the 39pF condition and since we want 50MHz the reactance required is 81.6Ω. This is an inductance of 0.259μH nominal.

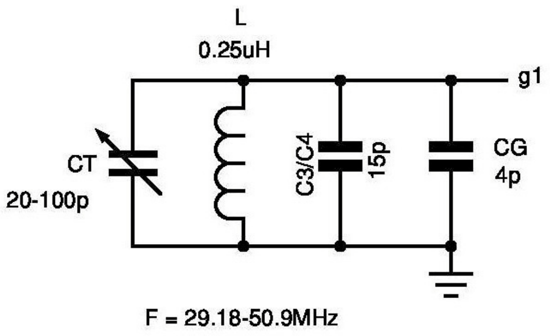

Figure 5 Circuit constants

To check that the frequency coverage is correct we now calculate what the reactance of a 0.259μH inductor is at 30MHz. It is 48.82 Ω and this corresponds to a capacitance of 108.6pF. This is less than the maximum effective capacitance of 119pF so the capacitor will be slightly less than fully meshed. The effective values for L and C are shown in Figure 5.

These calculations confirm the oscillator should cover the frequency range required. If there is a small stray capacitance we haven't taken into account then a small reduction in the inductor value will cater for this. Alternatively we can add a variable "*padding capacitor*" of a small value across the network for fine tuning, taking into account the effect this has on the total capacitance across the inductor. A 20pF maximum air variable trimmer would be a good choice. This means we need to reduce the inductor value by a small amount to compensate for this capacitor when set to about mid value, say 10pF effective.

> In variable LC oscillators that have to cover a wide range then the inductor is adjusted at the lowest frequency with the tuning capacitor fully meshed and the padding capacitor at the highest frequency. By alternating between the two ends of the range the tuning can be correctly adjusted to cover the minimum and maximum frequency correctly.

Temperature stability

All practical components exhibit a change in value as their temperature varies. As the components get warm in use, either due to the heat from the tube or the current flowing in them, then they will change in value by some amount. The ambient temperature at switch on is normally low but as the oscillator runs the temperature rises slowly and some warm up drift is likely to occur.

The inductors used generally have a strong positive temperature coefficient. As the temperature rises the inductance will increase in value due to the metal used expanding slightly. This causes the reactance to also rise and the result is the frequency drifts lower as the temperature increases, if the capacitor reactance and hence the value remains constant.

To counter this drift the capacitors are usually chosen to have an equal and opposite temperature coefficient. This means they need to have the correct negative temperature coefficient. These capacitors are chosen from standard values with a N150, N220 or higher temperature coefficient. If the two temperature coefficients are the same then drift from cold to full operating temperature is virtually eliminated. The number in N150 is the "*parts per million*" they change per degree Celsius rise in temperature.

The capacitors used also have to be a low loss type of a suitable construction, voltage and current rating for the application frequency required. Normally mica, ceramic or polystyrene types are chosen for the parameters. Polystyrene types are not suitable for very high frequency applications (above about 10MHz). Often a mixture of mica or ceramic types are used with different temperature coefficients to combat the thermal changes over the envisaged operating temperature range.

Air variable capacitors have a strong to medium negative temperature coefficient as they also suffer from some mechanical expansion as they warm up. In some cases the negative temperature coefficient is greater than the inductor positive coefficient so some of the capacitors may need to be positive types, for example P100, to keep the net temperature coefficient close to zero. There are special positive-negative temperature coefficient air variable trimmer Capacitors that can be adjusted to have a constant capacitance value but a temperature coefficient that can be changed from positive to negative coefficient by adjusting the trimmer. Oxley made "*Tempa-Trimmers*" for this application.

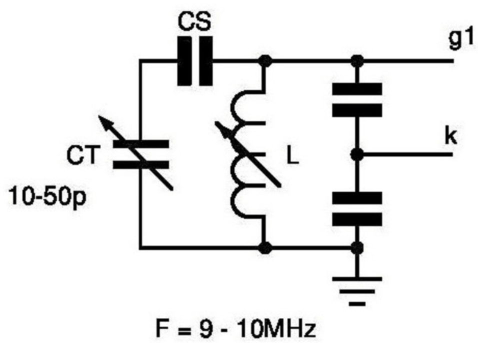

Figure 6 Reducing the tuning range with series capacitor

In oscillators that do not require a wide variation in frequency then often a suitable air variable capacitor is not available. A simple way to reduce the effective tuning range is to connect a capacitor in series with the tuning capacitor to reduce its swing.

Additional circuitry

If we look at Figure 1 again we can see what some of the other components are used for. The quiescent biasing is determined by the grid 1 to cathode voltage and this is determined by the value of the cathode resistor RK. For a grid bias voltage of, say, -3V to set the correct bias conditions the voltage drop across the cathode resistance is the same value so the cathode sits at +3V above ground.

This value can be determined by perusing the anode current versus grid 1 bias voltage for the tube in use at the chosen anode voltage. The resistor value at the required anode current is then calculated using Ohms Law. For the non-oscillating state the bias is set to be in the Class A range with a medium level of anode current flowing. When the oscillator starts the anode current is driven up to a higher value, but it must remain within the safe operating conditions for the tube chosen.

The RF choke in series with the cathode and its decoupling capacitor to ground serves to stop the RF being shunted to ground. The reactance value of the RF choke is normally selected to be at least ten-times higher than the output Z of the stage. Since this is relatively low almost any practical RF choke has enough reactance. In some low frequency oscillators a cathode resistor is not required as the RFC if it is a fairly high value has significant resistance, sufficient to provide the correct voltage drop to suit the tube used.

The anode of the tube must be held at close to zero RF potential to ensure correct operation. The value of decoupling capacitors are normally quite tolerant as long as they are large enough in value for the lowest frequency of operation. In this case a 10nF capacitor will serve for frequencies as little as 5MHz and above to about 100MHz. (A 10nF capacitor at 5MHz has a reactance of 3Ω and is close to being a short circuit to RF signals). Above this frequency a smaller capacitor will suffice, such as 4.7nF or 1nF.

The output can be taken from the cathode via a suitable dc blocking coupling capacitor. For best frequency stability the oscillator should feed a high impedance device such as another cathode follower with a small value coupling capacitor. For 30MHz a 1nF capacitor is more than big enough feeding a cathode follower stage and often as little as 10pF will suffice. By selecting the coupling capacitor value with the cathode follower grid resistance the level into the buffer amplifier stage can be set to the required value. It forms an attenuator network or voltage divider.

A small coupling winding on the main tank coil can transfer the signal to a high Z amplifier stage. Alternatively a second inductor with a resonating capacitor can be positioned close to the main inductor to form an air cored transformer with loose coupling. This method is show in Figure 7.

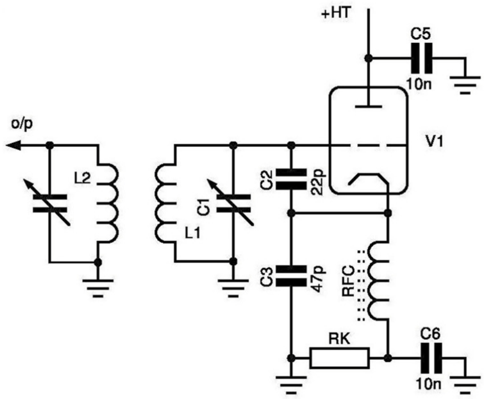

Figure 7 Transformer coupling for the output

Harmonic output

One of the characteristics of limiting oscillator stages is the purity of the sine wave output. Since the oscillator is basically running in Class C it is a non-linear amplifier and has harmonics present in the output. If a 'scope is used to look at the output waveform it is normally distorted because of the harmonics present.

The signal at the grid is however more like a pure sine wave as the tank circuit acts as a high Q filter. The amount of signal you can extract from this point is much less than from the cathode as any significant loading will reduce the feedback signal and it can cause the oscillator not to run if too much coupling is attempted.

The unloaded Q of the inductor should be as high as possible by the winding method and gauge of wire. For best frequency stability the loaded Q needs to be fairly high and this means thick wire and rigid construction are essential where high stability is the main criteria.

Freedom from "*microphonics*" is also a problem if the construction is less than rigid. Vibration and tapping on the enclosure containing the oscillator will cause jumps in frequency if the inductance is subject to vibration.

Another factor is the regulation of the anode supply voltage. For maximum frequency stability this should be regulated as tightly as possible. A variation in the anode voltage causes a change in frequency, so a well regulated supply is normally necessary to counter any variation in the raw dc supply voltage due to variations in the mains voltage. Any significant ripple on the anode voltage supply will causes residual FM which causes modulation in frequency and phase of the carrier.

Variations on the Colpitts oscillator

In some applications the oscillator frequency needs to be multiplied to a higher frequency. Generally, where a higher frequency is required it is often better to use a low frequency oscillator and then to multiply up to the final frequency than try to construct an oscillator at the higher frequency. Higher frequency oscillators tend to drift more than a low frequency oscillator that is multiplied up.

One of the methods to incorporate the multiplier as part of the oscillator is to add a parallel tuned tank circuit to the anode of the oscillator stage. This however is not the correct way to solve the problem.

The Colpitts oscillator relies on the anode being firmly grounded to RF. If the grounding is removed its operation is upset. Plac-

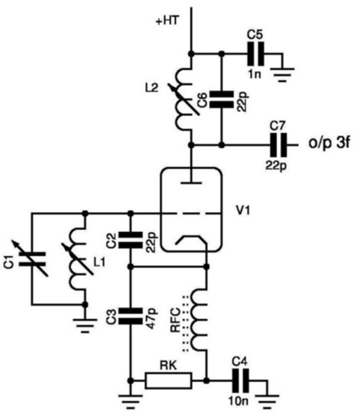

Figure 8 Frequency multiplier tank circuit in anode

ing a parallel resonant tank circuit at two-times or higher the oscillator fundamental frequency effectively removes the ground potential. This causes a loss of gain and an uncertainty of the degree of feedback.

The normal premise for choosing this method is that the Colpitts, like most self-limiting oscillators, has a high harmonic content as it is run hard into Class C.

Why not utilise this effect and pick off the harmonic of interest? Although to some extent it can be made to work with a narrow tuning range the derivation of the tapped capacitor values is a bit hit and miss and entails lots of empirical work. It may not work for a variety of tubes of varying emission and is best rejected as a method to use.

If this method is used then the oscillator output at the multiplied frequency is much lower in amplitude and if the tuning range is fairly wide it is common to find the oscillator ceases to run over the whole tuning range, as the feedback ratio has been upset by the modified circuit.

It is far better to use a separate stage as the harmonic multiplier. If one of the common dual triodes is used, (the 12AT7 is good for at least 100MHz as an oscillator or multiplier stage), the second half can be configured as the multiplier stage and the multiplier tank circuit is placed in the anode of this stage. This provides the necessary isolation and a high load impedance for the oscillator stage to work into. The level into the multiplier can be adjusted by the value of coupling capacitor used to optimise the multiplier efficiency. Alternatively a tube such as the 6U8/ECF82 is a triode-pentode combination and is also a suitable choice. The oscillator uses the triode and the multiplier stage the pentode section.

Band switching methods

When several ranges are required, for example in a home constructed RF signal generator, there are several methods used to change the resonating components.

In professional signal generators the coils and padding capacitors are normally mounted in a type of turret mechanism that rotates and connects the required components into circuit. This is a complicated method and where the highest performance isn't necessary then simpler methods can be used with normal multi section wafer switches.

One of the simplest methods is to use several inductors that can be connected in parallel with the main inductor. Inductors in parallel act in the same way as resistors in parallel. If the main inductor is chosen to be, say, 10µH and the tuning capacitor is a dual gang type with two equal sections then with one additional inductor up to three ranges can be arranged.

For the lowest frequency range both gangs of the tuning capacitor are paralleled and a single 10µH inductor. If the tuning capacitor is a 365pF per section then when fully meshed it will be 730pF and this with the inductor and capacitor divider will tune to some low frequency, typically about 1.9MHz. For the next range only one section of the tuning capacitor is used. The lowest frequency will be approximately twice the first range and highest also twice the first range. It is possible to cover, say, 2MHz to 5MHz for the first range and 4MHz to 10MHz for the next range with a useful amount of overlap.

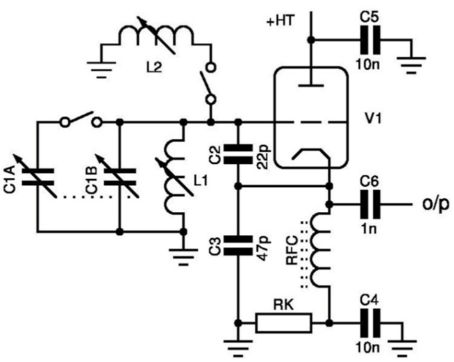

Figure 9 Band switching with shunt inductor

For the third range an additional inductor is added in parallel to produce an effective inductance of 2.5µH. This range has only one tuning capacitor section used and it will cover from 6MHz to 16MHz approximately. The basic circuit is shown in Figure 9.

This method may also require the capacitor divider values to be changed at some point in the various ranges. Again this can be by having several identical capacitors in parallel for both of the divider capacitors, so the ratio is constant. It may need 2 x 220pF for the bottom capacitor and 2x 100pF for the top capacitor for the lowest frequency range. For the highest range only one of each value is required and the others are switched out of circuit These effective values need to be included in the inductor calculation to obtain the required lowest frequency and frequency swing with the tuning capacitor and the padding capacitors for each range.

This method is attractive as the switching is simplified and the inductor values are sensible and requires less inductors than the other methods employed, although the calculations are more involved to arrive at a workable solution.

Crystal oscillators

Where a very high stability oscillator is required for a fixed frequency then the Colpitts oscillator using a crystal is simple to arrange. The crystal replaces the normal LC resonant network. This means it is best with a "*fundamental crystal*" that mimics a parallel resonant network.

A quartz crystal can oscillate in two different modes, these are the series resonant mode and the so-called "*parallel resonant*" mode. In actual fact a quartz crystal does not have a true parallel resonant mode. What is commonly referred to is a series mode crystal that has been pulled slightly lower in frequency so it appears to be inductive. To make it into a "*parallel resonant*" crystal requires a specific value of shunt capacitance so it can behave as a very high dynamic resistance.

The frequency difference between the series and parallel mode is about 0.0001% in frequency terms. A nominal 10MHz series resonant crystal when pulled with the correct shunt capacitance will oscillate at about 9.9999MHz.

The so-called "*fundamental*" or "*parallel resonant*" crystals are series mode crystal ground very slightly higher in frequency so that when pulled lower it is on the required frequency. The danger is that if the feedback network is incorrect it can jump from one mode to the other and generate spurious signals in the output or it may not oscillate at all.

For series mode oscillators, it is imperative to have some means of suppressing the "*parallel mode*" should the oscillator tuning be incorrectly aligned. A simple way is to shunt the crystal with a low value resistor of about ten-times the ESR of the crystal. Most fundamental series mode crystal have an ESR of not more than 68Ω and a 680Ω 1/4W resistor is normally suf-

For a fundamental crystal operated as a parallel resonant network then the capacitor value appearing across the crystal has to be a specific value, which the manufacturers will specify. Common values are 20pF to about 60pF. The oscillator therefore needs to present to the crystal the correct "*operating capacitance*". The fine adjustment of the frequency is performed by a variable capacitor to bring the shunt capacitance to the correct value. Normally this is determined during alignment by measuring the frequency of oscillation whilst adjusting the crystal trimmer capacitor.

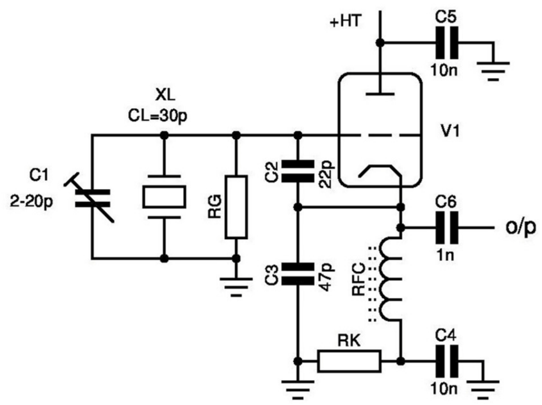

Figure 10 Crystal controlled Colpitts oscillator

Since the shunt capacitance required is quite a low value then the oscillator connection point to the crystal has to take into account the tapped capacitor values as these appear across the crystal terminals. However, in some cases the effective value of the tapped capacitor plus the grid-cathode capacitance is often more than the crystal needs to have to oscillate on the correct frequency. This can be alleviated by placing a series capacitor between the grid of the tube and the crystal, its value chosen to give the correct shunt value. The crystal trimmer also appears across the crystal so this value also has to be considered.

A typical Colpitts crystal oscillator is shown in Figure 10. This uses a 30pF load crystal.

The crystal requires a shunt capacitance of ≈30pF to resonate on the correct frequency. The capacitance appearing across the grid terminal to ground is the tapped capacitors in series of an effective value of ≈15pF plus the grid-cathode capacitance of 4pF. This is a total of 19pF plus any stray capacitance that may exist. Since this is likely to be about 2pF then the effective capacitance appearing across the crystal is ≈21pF.

The crystal needs 30pF to run on its correct frequency, so an additional ≈9pF needs to be provided by the trimmer capacitor C1. This is a 20pF maximum trimmer so it will be approximately midway at the correct setting. In this case no series capacitor is needed to reduce the grid capacitance as it is already less than the 30pF required. If the tapped capacitors are larger, say a 100pF and a 220pF in series this gives a shunt capacitance of about 90pF plus
the grid-cathode capacitance of 4pF. In this case a suitable series capacitor between the grid and the crystal of about 22pF would lower the total to less than 30pF and the rest is provided by the 20pF trimmer.

The other component required is a resistor between the grid and ground to complete the dc path for the grid current. In the previous oscillators shown this dc path was provided by the inductor so no resistor was needed. This resistor can be a fairly high value, a value of 47kΩ to about 30kΩ will generally be correct. The higher the value of grid resistor the more negative bias will be generated to turn off the tube at full drive level. This resistor cannot be too low in value as it will cause some damping of the voltage across the crystal if it is too low a value. The RD of a typical parallel mode crystal of 10MHz is about 100kΩ to several MΩ.

In some schematics the grid resistor is replaced with a high value RF choke. The danger is that this can also resonate at some other frequency with the associated circuit capacitance and the oscillator can attempt to run on two different frequencies, which will produce high spurious signal levels because the oscillator running in Class C also makes an efficient mixer. If a RF choke is used then it must be shunted by a resistor to damp out any spurious oscillation tendencies. This rather precludes the use of a RF choke as a resistor is normally reasonably non-inductive and has no significant spurious resonant modes.

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Meet Mr. FET ... the Transistor That Thinks It's a Tube
February 1967 Popular Electronics

Yesterday was the 71st anniversary of the announcement of the transistor's invention by Drs. Shockley, Bardeen, and Brattain at Bell Labs, but it was a Sunday so not as many RF Cafe visitors saw the commemorative title graphic I used. Their transistor was a current-controlled signal amplifying device as opposed to the field-effect transistor (FET) which is a voltage-controlled signal amplifying device - as is the vacuum tube. I never thought about it before, but maybe that had something to do with the electronics world's hesitancy to adopt the transistor as a replacement for the tube. Early in the transistor's history, practical applications were limited due to low reliability, low power handling, low frequency, lack of ruggedness in harsh operating conditions, and other shortcomings compared to established and much refined vacuum tubes was reason enough to shun the new fangled technology, but that current-controlled thing could have been a barrier inhibiting adaptation as significant as any of the aforementioned obstacles. By the time FETs became widely available for commercial use, the transistor vs. tube battle was already tipping in favour of the transistor. FETs initially enjoyed a huge cadre of cheerleaders in the digital circuit realm due to their extremely low power consumption. One of the most notable uses of FETs in the analogue world was as high impedance inputs to opamps and voltmeters.

Meet Mr. FET ... the Transistor That Thinks it's a Tube

By Louis E. Garner, Jr., Semiconductor Editor

This Little Fellow and His Family are Taking over Solid-State

It's hard to imagine, in the light of present scientific and technological achievements, that just a few short years ago there were no transistors and no integrated circuits. In fact, there are still many old-timers who remember the "prehistoric" age when there were no vacuum tubes, either. In those days, radio transmitters were weird spark-sputtering electromechanical monsters which bore a nostalgic resemblance to the fire-eating dragons of a yet earlier era.

Radio receivers were simple, too. A huge antenna hooked up to a couple of oversized coils, a tiny bit of mineral-galena - with a cat's whisker (fine wire), a pair of headphones ... and that was the receiver. The galena, a crystal detector, was cheap, but it was insensitive and temperamental, too. It was on a quest for a better detector that Prof. J. A. Fleming developed the diode vacuum tube which, rightly enough, came to be known as the "Fleming valve."

A short time later Dr. Lee De Forest, inventor and scientist, added the control grid which, for the first time, enabled the vacuum tube to amplify, oscillate and detect electrical signals.

With the development of the vacuum tube came a giant industry with a record of spectacular achievements in radio broadcasting, electronic surveillance, computer technology, and industrial control. During the course of this industrial revolution, the vacuum tube was enlarged, miniaturized, modified and refined in many ways, including the addition of more electrodes. But there was a proverbial fly in the ointment. Most tubes generated so much heat that they had a relatively short useful life, and this resulted in a high failure rate for tube-type electronic equipment.

Then, early in 1948, Drs. Shockley, Bardeen, and Brattain - all scientists at the Bell Telephone Laboratories - announced the invention of a completely new device: a triode "crystal" which they claimed could amplify as well as detect electrical signals. Dubbed a Transistor (from TRANsfer and reSISTOR), the device was nothing more than a tiny cube of crystalline semiconductor material with two fine wire cat's whiskers. A minute voltage applied to the base crystal (thereafter called the base) con-

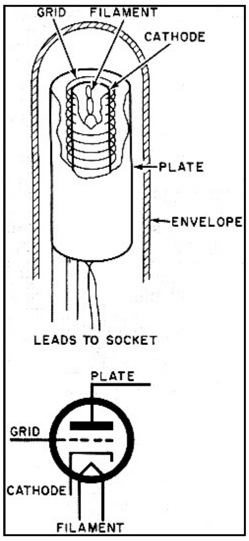


Fig. 1 - Cutaway view illustrates the internal construction of a triode vacuum tube. The schematic symbol representing this tube is shown below the cutaway view.

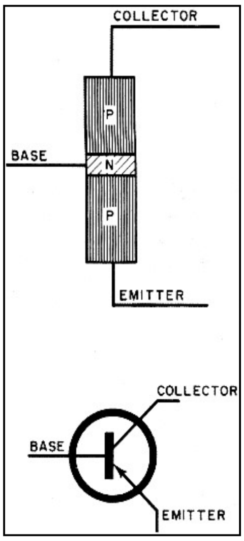


Fig. 2 - Basic junction transistor cross section shows sandwich arrangement of semiconductor material for pnp unit. Note direction of arrow in the schematic symbol.

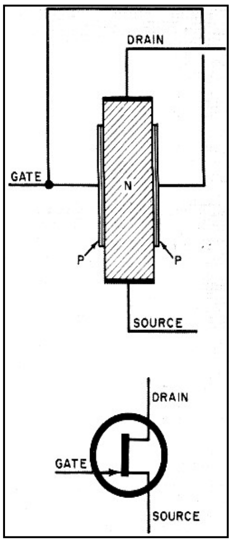


Fig. 3 - Cross section of n-channel junction field-effect transistor shows p-type regions diffused into n-type substrate. Symbol has not been fully standardized yet.

trolled a much larger current flowing between the two whiskers, one of which was called the emitter, and the other a collector. The early transistors were expensive, noisy, and not too reliable. But these disadvantages were offset by their extremely small size, high efficiency and, potentially at least, manufacturing simplicity.

By 1951, long before this early point-contact transistor posed even a mild threat to the supremacy of the vacuum tube, a radically new type of transistor, the now common and widely used junction transistor was introduced.

Of Tubes and Transistors. Although a godsend in many ways, transistors brought a host of new problems to circuit designers. Essentially a current amplifier, the device could not be used as a direct replacement for the vacuum tube, which is a voltage amplifier. It had a low-to-moderate input impedance in contrast to the very high input impedance of vacuum tubes. In addition, because the transistor has a direct resistive connection between its input (base) and output (collector) terminals, a multiplicity of circuit feedback problems had to be solved.

Improved design methods were developed later, and transistorized receivers, amplifiers, transmitters, hearing aids, toys and industrial controls were produced in vast quantities. But there were still many circuit requirements where only high-impedance vacuum tubes could fill the bill, and many designers yearned for a miracle-like device - a transistor with tube-like characteristics.

As time went by, transistors got better and better. Output voltage and current ratings were being extended, as were the upper operating frequency limits. But no matter how the newer transistors were improved, they still had the basic characteristics of earlier types.

Meanwhile, back at the laboratory, scientists were experimenting with a new solid-state device, based on a molecular principle described by Lilienfeld as far back as 1928. Shockley, one of the co-inventors of the original transistor, had proposed a practical transistor-like device based on Lilienfeld's principle as early as 1948, but it was not until the mid 1950's that a workable device was developed in the laboratories, and practical, reliable units were not manufactured until the early 1960's.

The new device combined the most desirable features of the versatile vacuum tube and the efficient transistor. It had high input impedance and offered good isolation between input and output electrodes. Capable of high gain, it was, at the same time, as small as conventional transistors and extremely efficient. And, oddly enough, it exhibited at least one of the important operating characteristics of the vacuum tube - the control of a current by means of a varying electric field - in a solid-state medium rather than in a vacuum.

Identified by a variety of names - Fieldistor, unipolar transistor, and so on - during its gestation period, the device is now known as the field-effect transistor (FET). It is, indeed, a transistor which "thinks" and "acts" like a tube.

Meet Mr. FET. Pictorial and schematic representations of a triode vacuum tube, junction transistor, and field-effect transistor are illustrated in Figs. 1 through 3. Of the three schematic symbols, the FET symbol is the least standardized at present.

In a vacuum tube (Fig. 1), the plate current is simply a flow of free electrons which are literally "boiled" off of the cathode by the heated filament (in some high-power tubes, the filament is used directly) and are attracted by the positively-biased plate. The electrons leaving the cathode must travel through the intervening grid.

A negative bias on the grid establishes an electric field which tends to repel the electrons flowing from cathode to plate, limiting the plate current. The plate current can also be controlled, within limits, by the plate voltage. However, since the grid e is much closer to the cathode than the plate, a smaller variation in grid voltage has essentially the same or greater effect on the plate current as a larger variation in plate voltage. It is this characteristic that e-ables a vacuum tube to amplify a signal.

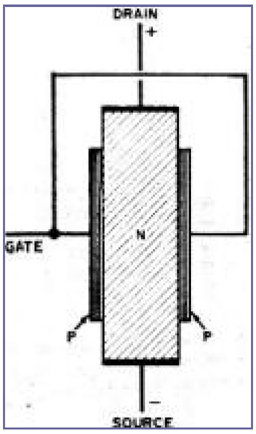


Fig. 4 - Diffusion of p-type regions into n-type substrate provides a means of controlling the current flow between source and drain elec-

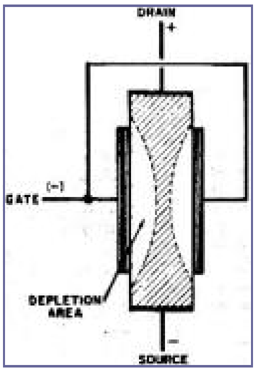


Fig. 5 - When gate is reverse-biased, an electric field is set up to repel the current carriers, creating a depletion area and restricting region in which current flows.

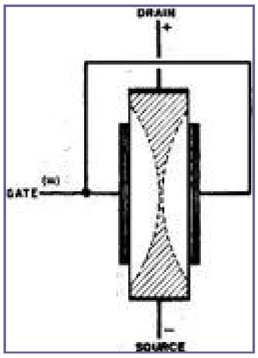


Fig. 6 - As the reverse gate bias is increased, depletion areas spread into the channel until they meet, creating an almost infinite resistance between source and drain.

Plate current saturation occurs when the plate is attracting all available free electrons. When this point is reached, a further increase in plate voltage does not cause a corresponding increase in plate current.

The basic junction transistor (Fig. 2) consists of three sandwich layers of two different semiconductor materials. Here, the emitter-collector current consists of a movement of two types of particles: electrons, which are negatively charged, and "holes" (essentially, the absence of an electron in an otherwise stable crystalline structure) which carry a positive charge. If the electrons predominate, they are called majority carriers and the holes minority carriers, with the material identified as an n-type semiconductor. By the same token, a material in which the positive holes predominate is called a p-type semiconductor.

The transistor's emitter-collector current is controlled by the injection of minority carriers into the base region. Since the base is quite thin, a relatively small current change there can control a much larger emitter-collector current. The junction transistor, then, is a current amplifying or control device, in contrast to the vacuum tube, which is essentially a voltage amplifier. In addition, since a base current flow, however minute, is essential to operation, the device must have a low input impedance.

The basic field-effect transistor consists of a slab of either n- or p-type semiconductor material with an electrode at either end, and two electrodes along the sides as shown in Fig. 3. Observe that the side electrodes are tied together and thus function as a single element. By convention, the terminal into which current is injected is called the source, and the output terminal is called the drain. The remaining electrode, which serves as a control element, is called the gate. Notice how FET terminology thus differs from that of both vacuum tubes and junction transistors.

How the FET Works. The basic junction FET (JFET) is essentially a bar of doped silicon that behaves like any ordinary resistor. Refer to Fig. 4 and assume that the FET is made up of an n-type substrate (material). Then, current through the device will consist principally of electrons as majority carriers. Consider what happens when a d.c. voltage is applied to the source and drain electrodes, while the gate is at zero bias. Under these conditions the device behaves more or less like an ordinary resistor. Within limits, source-drain current flow is directly proportional to applied voltage.

Now suppose a reverse bias is applied to the gate. (This would be a voltage of the same polarity as the majority carriers; that is, negative for n-type material, positive for p-type material.) The gate voltage would then set up an electric field to repel the current carriers, and restrict the region through which they flow. This action is shown in Fig. 5. In essence, the current-carrying channel is depleted of current carriers within areas immediately adjacent to the gate electrode. Logically enough, the regions where current movement is restricted are termed the depletion areas (sometimes referred to as zones or regions rather than areas).

A further increase in the reverse gate bias further expands the depletion areas, as shown in Fig. 6, further reducing drain-to-source current. Thus, with a given fixed gate bias, the drain current will vary with the signal applied to the gate. Note, also, that since the gate is reverse-biased, the FET has a very high input impedance when there is little or no drain current flow. The FET behaves much like a vacuum tube in that drain current is controlled by an electric field set up by the gate voltage.

Consider what happens when the gate bias is zero and the source-drain voltage is gradually increased. Up to a point, drain current will increase linearly as in a resistor. However, the drain current flowing along the channel sets up an internal reverse bias along the surface of the gate. This, in turn, establishes an electric field which causes a gradual increase in the depletion areas similar to the effect produced by the application of an external gate bias. Eventually, the increase in the depletion areas, which tends to limit drain current, reaches the point where it counterbalances the drain current increase. From then on, there can be no further increase in drain current regardless of any further increase in drain-source voltage.

In effect, the drain current has reached saturation (that should be a familiar term!). The point at which this current limiting takes place is called the drain-source pinch-off voltage. And there is, as you might suspect, a pinch-off voltage for any given gate bias. With higher gate bias voltages,

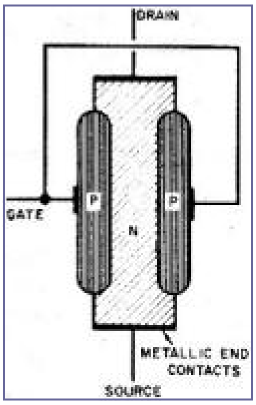


Fig. 7 - A JFET can be manufactured by diffusing p-type gates on either side of an n-type substrate, and then attaching suitable electrodes.

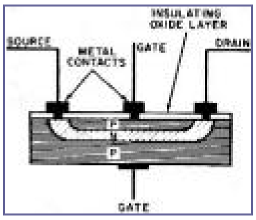


Fig. 8 - This junction FET features single-ended construction. Here, an n-type channel is formed on one side only of a p-type substrate by photo-masking, etching, and impurity diffusion processes. The surface is covered with an insulating oxide layer through which holes are cut for electrode connections.

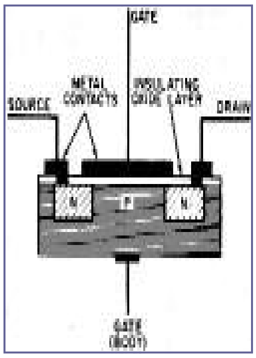


Fig. 9 - Cross-section view of insulated-gate field-effect transistor (IGFET) shows gate metal contacts insulated by a thin layer of oxide which, together with the semiconductor channel, forms a capacitor. The metal contacts serve as one plate while the substrate material serves as

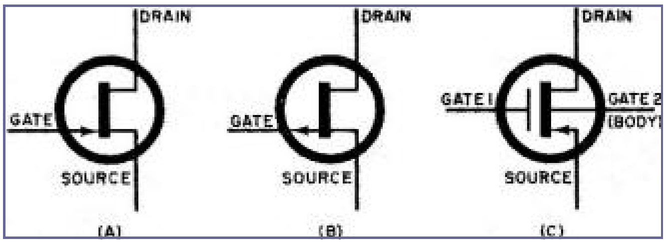


Fig. 10 - Schematic symbols currently used for field-effect transistors include (a) n-channel JFET, (b) p-channel JFET, and (c) one form of p-channel IGFET.

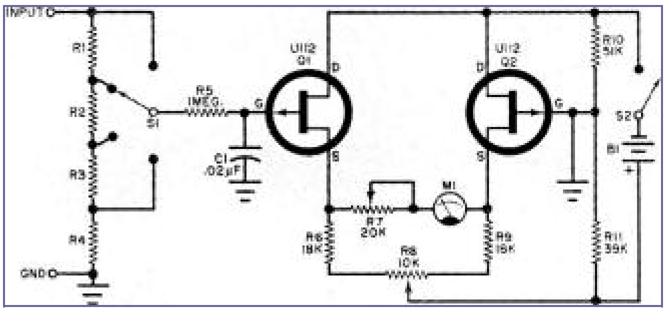


Fig. 11 - This FET voltmeter, featuring a matched pair of Siliconix U112 FET's in a differential amplifier arrangement, has a sensitivity of 0.5 - 1.0 volt full scale.

pinch-off occurs at much lower drain currents, of course.

If drain current is plotted against drain-source voltage for a given gate bias, a FET characteristic curve is developed. A family of such curves may be prepared by plotting drain-source current vs. drain-source voltage for a number of different gate bias voltages. When compared to corresponding families of vacuum tube characteristic curves, the typical FET is found to have characteristics which are virtually identical to those of a pentode vacuum tube.

The FET Family. Field-effect transistors are manufactured using techniques that are almost identical to those used in the manufacture of the familiar junction transistor. For example, a FET can be assembled by diffusing or alloying p-type gates on either side of an n-type substrate and then attaching suitable metallic electrodes, giving the appearance of Fig. 7.

From a production standpoint, it is often easier to carry out all diffusion and processing operations from one side of the substrate. This type of single-ended construction is illustrated in Fig. 8. Manufacture starts with a wafer of p-type material. Photo-masking, etching, and impurity diffusion processes form an n-type channel on one side of the material. A p-type gate is then diffused into the n-type channel, and the entire surface is covered with an insulating protective oxide layer, with holes etched through the oxide for the final metallic electrode connections.

If you have been wearing your "thinking cap," you may be wondering, at this point, just why the gate electrode is joined electrically to the channel material. After all, the gate is reverse-biased in use, causing the p-n junction to behave as if it were a dielectric. Furthermore, the operation of the device is based on the presence of a varying electric field on the gate and not upon the movement of current carriers from the gate to the channel region.

So, why not insulate the gate? Good question, but someone else thought of it before. As a matter of fact, insulated-gate FET's (IGFET's) are actually being produced by several major manufacturers. One type of construction is illustrated in Fig. 9. Here, the gate is insulated by a thin layer of oxide. The gate metal area is overlayed on the oxide and in conjunction with the insulating oxide layer and the semiconductor channel forms a capacitor. The metal area serves as the top plate of the capacitor, while the substrate material is the bottom plate.

In some cases, the IGFET's are assembled as tetrode devices, with the substrate body (often identified as gate 2) connected to a separate electrode. Since the drain and source are isolated from the substrate, any drain-to-source current in the absence of gate voltage is extremely low because, electrically, the structure is equivalent to two diodes connected back to back.

JFETS FOR THE EXPERIMENTER

The following low-cost audio, r.f., and general-purpose junction field-effect transistors are suitable for experimenter projects

MANUFACTURER	TYPE	DESCRIPTION	PRICE	ORDER FROM
Motorola Semiconductor	HEP-801	n-channel	$3.39	Allied Radio Corp.
Products, Inc.	MPF103	n-channel	1.00	100 N. Western Ave.
P. O. Box 955	MPF104	n-channel	1.00	Chicago, Ill. 60680
Phoenix, Ariz. 85001	MPF105	n-channel	1.00	
Siliconix, Inc.*	U110	p-channel	1.00	Bill Shipe
1140 W. Evelyn Ave.	U112	p-channel	1.00	Siliconix, Inc.
Sunnyvale, Calif. 94086				
Texas Instruments, Inc.	2N3819	n-channel	3.75	Lafayette Radio Electronics
13500 North Central Expressway	2N3820	p-channel	3.75	111 Jericho Turnpike
Dallas, Texas 75222	TIS34	n-channel	3.75	Syosset, L.I., N. Y. 11791

*FET circuit ideas and applications data available without cost on request

Table 1 - JFETs for the Experimenter

Insulated-gate FET's have extremely high input impedances - higher, in fact, than many vacuum tubes - but are very sensitive to stray electrical charges and can't be destroyed by body static. Input impedances higher than 10 million megohms are not uncommon. Manufacturers generally wrap IGFET leads in metallic foil, or supply them with the leads held together by a metal eyelet as a protective measure. Extra care must be taken during installation, wiring, and testing of the IGFET to prevent its destruction.

The junction field-effect transistor (JFET) shown in Figs. 7 and 8 can be made as an n-channel or a p-channel device. As with conventional junction transistors, JFET's are identified by the slightly modified schematic symbols shown in Figs. 10(a) and 10(b). With the source considered common, an n-channel FET requires a positive drain voltage and a negative gate bias; the p-channel FET is operated with a negative drain voltage and a positive gate bias.

As shown in Fig.10(c), the IGFET is identified by an entirely different symbol. This general type of FET is offered in two basic forms and in many individual types with different electrical specifications and operating characteristics. Unlike the JFET, however, a given IGFET may require either a positive or negative gate bias, with respect to its source, depending on mode of operation.

In addition to regular FET's, light-sensitive FET's are being produced by a number of manufacturers. Called photoFET's, they are similar to conventional FET's but are equipped with transparent lenses that focus external light on their sensitive surface areas. The photoFET can be up to ten times as sensitive as a junction phototransistor, and has a better gain bandwidth factor, in addition to offering exceptional isolation between input and output circuitry.

Terminology. As with any new technology, a number of terms are used to describe FET devices, and their characteristics. Some terms are used primarily by manufacturers, others chiefly by circuit designers. Unfortunately, the terms and symbols have not yet been fully standardized, with the result that different manufacturers may use different terms and symbols to represent the same thing.

During its early developmental stages, the FET was identified by different names. At various times it has been called a Fieldistor, UNIFET, and Unipolar field-effect transistor. The UNIFET and Unipolar terms were derived from the single-junction construction of the FET as contrasted to the two-junction (or bipolar) construction of the junction transistor.

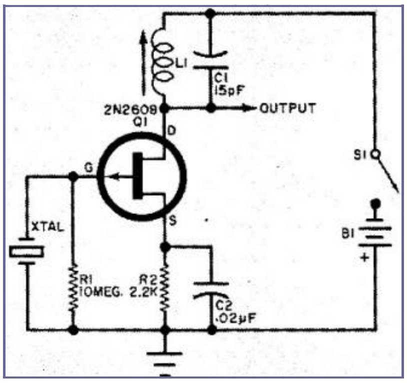


Fig. 12. This high-frequency crystal-controlled oscillator employing a Siliconix 2N2608 p-channel FET has a useful operating range of 1 megahertz.

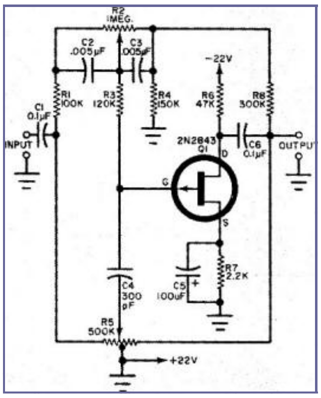


Fig. 13. Modified Baxandall hi-fi tone control employs a single p-channel FET (Siliconix 2N2843). Separate bass and treble controls are provided.

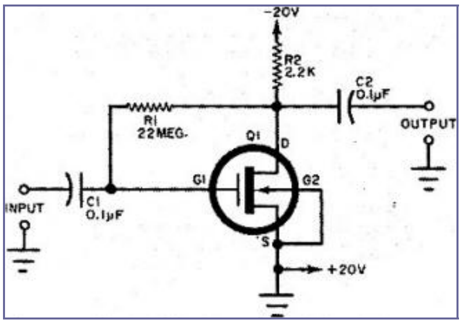


Fig. 14. Definitely not recommended for the experimenter, this single-stage preamplifier features an insulated-gate field-effect transistor (IGFET).

The name Fieldistor is practically obsolete today. And so are the other names, although one firm still refers to its products as UNIFETS. Generally, junction-type units are simply referred to as FET's, although some firms use the more specific designation JFET.

Insulated-gate field-effect transistors are also called MOSFET's in recognition of the importance of the metal-oxide-semiconductor (MaS) insulating film used in their construction. But some de-signers refer to the same device simply as MOST. The latter could lead to an expression such as "Gosh, Mr. FET, you're the MOST."

At times, the full expressions used to identify a specific transistor may assume an awe-inspiring length. For example, a data sheet from one firm identifies a specific unit as a - hold your breath - low-noise, n-channel epitaxial planar silicon tetrode field-effect transistor!

In addition, not all manufacturers describe their products using the same specifications. A parameter which is considered important by one company may be completely ignored by another. As a general rule, however, the majority of manufacturers do give maximum voltage ratings, input and output capacitances, maximum power dissipation, and typical gate cutoff current. Many even specify the common source forward transconductance (in µmhos, as in tube specifications) for typical operating conditions.

Naturally, references are still made to n-channel or p-channel types, as well as to enhancement or depletion modes of operation. The fact that both n- and p-channel types are available permits FET's to be used in a variety of complementary circuits, a characteristic that FET's do not share with vacuum tubes.

Some firms, in striving to simplify matters, have adapted type designations to indicate the intended mode of operation of the device. Thus, Type A FET's are characterized for depletion-mode operation; Type B are intended for either depletion or enhancement modes; and, finally, the Type C designation is reserved strictly for enhancement-mode types. But please don't confuse these designations with Class A, B or C amplifiers!

Typical FET Applications. With high input and output impedances and other tube-like operating characteristics, FET's may be considered as almost the solid-state equivalents of vacuum tubes, and can be used in virtually identical circuits, provided power ratings are observed. The common source configuration is the most popular, and corresponds to the common-cathode tube circuit arrangement. Typical FET circuits are illustrated in Figs. 11 through 14.

Figure 11 is a FET voltmeter with a matched pair of p-channel FET's (Q1 and Q2) used in a differential amplifier arrangement. In general, FET voltmeters compare favourably with good-quality VTVM's.

A high-frequency crystal-controlled oscillator employing a p-channel FET is shown in Fig. 12. .Gate bias is provided, as in a vacuum tube circuit, by source resistor R2, bypassed by C2. The feedback needed to start and sustain oscillation is furnished by the FET's inter-electrode capacity as well as by stray wiring capacities.

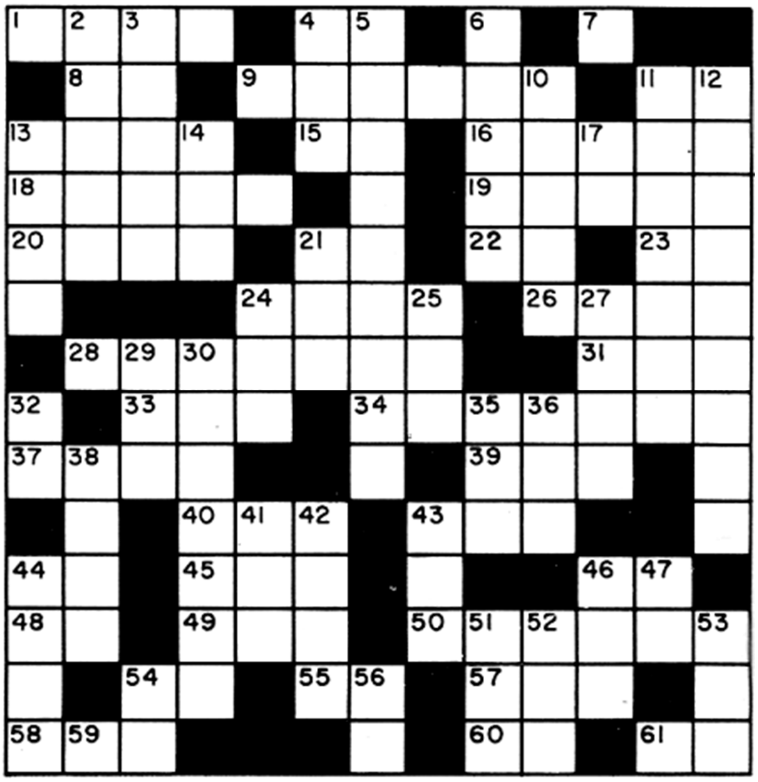
Figure 13 features a single p-channel FET, Q1, in a modified Baxandall hi-fi tone control circuit which can be used as part of a stereo control centre. Potentiometer R2 serves as the bass control, and R5 as the treble control.

Finally, a simple preamp circuit using an IGFET (MOSFET, or MOST, take your choice) is given in Fig. 14. Here, gate bias is provided by a 22-megohm resistor, R1, returned to the drain electrode.

These circuits illustrate a few of the many practical applications of the FET. They are not intended for use in construction projects as shown, since some component values might have to be changed to compensate for the use of different FET's. In any case, only an experienced technician should attempt to use an IGFET in the application shown in Fig. 14. Practical FET projects will be covered in future issues.

One thing is certain: Mr. FET is a real "comer," and should have a brilliant future!

Electronics Crossword



Across

1. 1/746th of 1 hp.
4. Lower than r.f. (abbr.).
7. 1000 (abbr.).
8. French article.
9. Voltage on an electrolytic causes it to be ---.
11. TV frequency band (abbr.)
13. Used in drills.
15. Pilot light (abbr.).
15. Maurice isn't here (slang).
18. Si, Jah, Oui.
19. Borer.
20. Chew.
21. Tube characteristic.
22. Spanish agreement.
23. Telemetering (abbr.).
24. Demeanor.
26. Oriental nurse.
28. Insects and radio sets have one.
31. Time gone by.
33. Unit of work.
34. TV band assignment.
37. Against.
39. Regret.
40. German electrician.
43. Deed_
44. 2п FL.
45. Two (comb. form).
46. Electronic test set.
48. 1050 (Roman style).
48. Electric driving force.
50. Tube book.
54. Estados Unidos (Eng. abbr.).
55. Gallic (abbr.).
57. As opposed to "min."
58. Voltage dropper (abbr.).
60. Amplifier output stage.
61. 1/6.28fC.

Down

2. Twiddle the trimmers.
3. Four (comb. form).
4. Charged particle.
5. Cycles per unit of time.
6. Affords.
10. Andrea ---.
11. E.M.F.
12. Resonator.
13. "Pokes" (coll.).
14. Mend.
17. Third note of scale.
21. Opposite of "max."
24. Million (comb. form).
25. Sloppy "no.".
27. On a horse's neck.
29. Type of "work" in radio.
30. Three-element tubes.
32. Current measure (abbr.).
35. Leaping current.
36. Fastener.
38. Point of balanced frequencies.
41. Could be a bad capacitor.
42. A thin silk made in Caucasia.
43. Motor winding (abbr.).
44. Transmitter (abbr.).
46. Light.
47. B fiat in Tartini's system of solmization.
51. Unit of electric current.
52. Sleep.
53. Used in making varnish.
54. We.
56. It travels at the speed of light (abbr.).

August Puzzle Answers:

R	O	B	O	T			N	O	I	S	E
I	D	E	S		U	S		F	R	I	A
G	E	T		C	R	O	P		A	G	C
S	R		G	O	N	S	E	T		S	H
		F	I	L			R	I	D		
C	R		N	O	V	I	C	E		T	O
L	U	G		R	A	S	H		A	S	H
I	S	L	E		N	O		D	R	A	M
P	H	O	N	E			D	X	E	R	S


SAIEE
HISTORICAL SECTION
SAIEE Historical Section celebrating South African Heritage Day - You are invited!
The legacy and history of South African electrical engineering innovation have been carefully curated for our current and future generations to learn, enjoy and come to appreciate the significant contribution to society of some of the giants of our field in years past. Many of the benefits we enjoy today will be better appreciated when you see the journey of technology and innovation towards the convenience and safety we currently enjoy and taken for granted.
The Johannesburg Children's Home, founded in 1892, which is the oldest charitable institution in the city, will participate as well as the Radio Hammies Club and the Urania Village community.
The Radio Hammies will demonstrate the international communication capabilities of our very own 'radio shack,' the ZS6IEE museum station in the Max Clarke Museum, and operated by the Antique Wireless Association of South Africa (AWASA).
Other sites of historical interest on the campus, such as the South African Radio Astronomical Society (SARAO) Telescope, built-in 1910, will be open for viewing.
It will be an open day, and we will have soft drinks, tea/coffee, pancakes, boerewors rolls, etc., on sale for visitors.
Bring the whole family for a very informative outing. See you there!
24 September 2022 | Max Clarke Museum, 18A Gill Street, Observatory, Johannesburg (entrance via Innes Road) | 09h30 - 15h00

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Antique Wireless Association of Southern Africa

Mission Statement

Our aim is to facilitate, generate and maintain an interest in the location, acquisition, repair and use of yester-days radio's and associated equip-ment. To encourage all like minded amateurs to do the same thus ensur-ing the maintenance and preservation of our amateur heritage.

Membership of this group is free and by association. Join by logging in to our website.

Notices:

Net Times and Frequencies (SAST):

Saturday 07:00 (05:00 UTC) —Western Cape SSB Net— 3.640; Every afternoon from 17:00—3.640
Saturday 08:30 (06:30 UTC)— National SSB Net— 7.125; Sandton repeater 145.700
Echolink—ZS0AWA-L
Relay on 10.125 and 14.135 (Try all and see what suits you)
Saturday 14:00 (12:00 UTC)— CW Net—7025

AWASA Telegram group:

Should you want to get on the AWA Telegram group where a lot of technical discussion takes place, send a message to Andy ZS6ADY asking to be placed on the group. This is a no-Nonsense group, only for AWA business. You must download Tele-gram App first. …..+27824484368

Mike ZS6MSW:
I will be reopening some CW Morse Code Classes in January 2023. Let me know if you are interested, and I will add you to the program.
One prerequisite is before you apply, and it's FREE, you need to begin becoming familiar 15 min per day, with the sounds of the character PRIOR to the class starting. This will prevent holding the classes up for those who are practicing.
Here are the following tools to get you started:
https://morse-runner.software.informer.com/1.6/
http://www.justlearnmorsecode.com/download.html
for the Android guys here are some recommended by me ZS6MSW
https://play.google.com/store/apps/details?id=uk.co.bitninja.kmtpro&hl=nl&gl=US https://apps.apple.com/us/app/morse-machine/id1455507957
You can email me zs6msw@gmail.com

If any of you are able to set some time aside twice a week and duplicate my offer, giving CW classes around the country I will deeply appreciate it. You can choose a different day also. Please let me know if you are able to advertise to your club. Keep me informed of your progress.