An Evaluation of Junction Field-Effect Transistors Suitable for Active Antenna Applications

by

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4 December 2008

Introduction

In the design of active antennas, the intermodulation distortion (IMD) and noise figure (NF) performance of the active devices are important design considerations together with cost and availability. Many designs that have been published in recent years claim to have good IMD performance, but one of these uses a low-power FET device that costs around $US20 each. Other designs are available that have improved performance, such as those making use of complementary pairs, and it may simply be a matter of the designers lacking sufficient information to make intelligent choices so as to arrive at finished designs having a performance/cost ratio that would be attractive to builders and which make use of devices which are available from popular distributors such as Digi-Key and Mouser at reasonable prices.

What's All This Linearity Stuff, Anyhow?

For HF frequencies and below, the IMD performance of an active antenna or receiver preamplifier is of primary concern as terrestrial and galactic background noise seen by the antenna are primary noise sources, while at the same time congestion, especially in the medium wave (MW) and shortwave (SW) broacast bands (BCB), results in IMD products that interfere with the reception of low-level signals. This is especially true when in close proximity to MW BCB stations which can generate harmonics in a poorly designed active antenna or receiver preamplifier. It is therefore essential that the designer of active antennas at HF frequencies and below gain a thorough understanding of how to select devices on the basis of superior linearity performance.

Performance factors such as breakdown voltages, power dissipation, and NF are typically available in manufacturers datasheets, however IMD performance is rarely available except by observing the characteristics of curve families on a curve tracer or by measuring the performance of the device in a circuit.

When using a curve tracer, there are a number of items that need to be carefully observed in order to ascertain the potential IMD performance of a given device. These include, but are not limited to, the flatness of the individual traces in the linear region, the straightness of the individual traces in the linear region, the uniformity of the spacing between the traces, the saturation voltage, and the transition between the saturation region and the linear region.

Curve families for FET devices (both JFET and MOSFET) are generated by applying a fixed gate voltage (V_{GS}) to the device and then varying the drain voltage (V_{DS}) while observing the drain current (I_D). For a device that has good linearity characteristics, these individual traces should be fairly close to horizontal and should remain straight between the saturation region and the avalanche (ie - breakdown) region.

The nature of the saturation region determines the 1dB compression point (P_{1dB}) of the device and has a direct impact on the input and output IMD products, often measured as OIP_3 and IIP_3, being the Third-Order Output Intermodulation Intercept Point and the Third-Order Intermodulation Intercept Point, respectively, though other definitions exist. The saturation voltage at the point where the design load line intersects the vertical drain current (I_D) axis determines the P_{1dB} characteristics of the device, and the smaller this voltage is the higher will be the P_{1dB} performance.

For most JFET devices, the transconductance (g_m) will change with the drain current (I_D). This can be seen by way of the spacing between the individual curve traces. The more uniform the spacing between the lines, the better the potential linearity of the device. Generally, g_m will increase as I_D increases as

FETs are generally sqaure-law devices, and the device should be biased away from the point where the variation in g_m becomes noticable.

JFET devices tyoically have relatively high saturation voltages, much higher than wuld be found in either bipolar of MOSFET devices. This is a characteristic of JFET devices that simply has to be lived with as it has a lot to do with the underlying semiconductor physics of the gate channel.

The portion of the curves that transitions between the saturation region to the linear region plays an important rôle in the linearity of the device. When making OIP_3 measurements, a region in the third-order IMD products is usually encountered where the IMD products rise above the straight 3-to-1 line, and this rise is referred to as "IR (Intermodulation Ratio) Expansion". If the transition from saturation to linear in the curve is sharp, then the IR expansion will be very small. However, the broader this transition zone is the higher the IMD products will rise above the 3-to-1 line.

Certain manufacturers of MMIC devices are overly zealous when representing the OIP_3 performance of their products, typically measuring the IMD products below the region of IR expansion and projecting the OIP_3 point from there, leaving the system designer to find out the hard way that the devices don't perform at all well at higher signal levels. Stanford Microdevices (later Sirenza Microdevices and now part of RF Microdevices) was infamous for this form of specmanship and one simply had to learn to leave them out of consideration.

A Bit of Transistor History

Most of the devices that are found to be suitable for active antennas and receiver front ends have been used extensively in the design of trunkline, multicoupler, and distribution amplifiers for the cable TV (CATV) industry. There are very few low-power FET devices that have found their way into designs outside of the CATV inducstry, however many small-signal devices such as the J309, J310/U310, and similar devices have seen extensive usage in commercial, military, and hobby applications. For example, the J309 when used as a common-gate amplifier could be easily configured to have a wide-band input impedance of 75-ohms when used with a source resistor of 220 ohms, which is very convenient and cost-effective.

N-Channel Devices

A series of ten N-channel devices are described here, all of which are currently available from Mouser at very reasonable prices. Fig. 1 displays a series of characteristic curves for each of these devices, while Table 1 lists some of the static characteristics as well as prices and sources for each.

From this series of characteristic curves, the tendency for g_m to increase with increasing drain current (I_D) is readily noticable. Devices within the BF244A/B/C family exhibit the least amount of variation, while the JEDEC (ie - 2N series) devices exhibit the most. It can also be seen that all of these devices have saturation characteristics that can best be described as poor, though the J309 is somewhat decent. From this aspect alone, it can be seen that none of these devices are practical for usage in applications that require exceptionally high IMD performance, however they can be used as input devices in conjunction with output devices such as bipolar transistors which have better saturation characteristics.

The BF244A and BF244B display the best linearity in terms of g_m uniformity (ie - uniform line spacing), as well as transition region characteristics. Despite their lower g_m values, their linearity for drain currents below 5mA and their low NF make them attractive for low-noise amplifiers at VHF frequencies. The same can-

(*continued on page 5*)

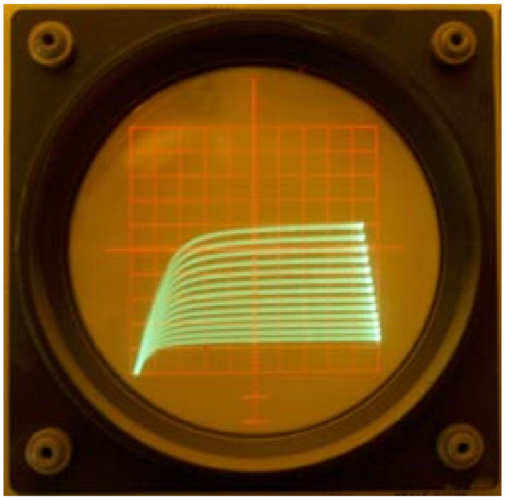

Fig. 1A - BF244A (100mV/step, vertical - 1mA/div, horizontal - 1V/div)

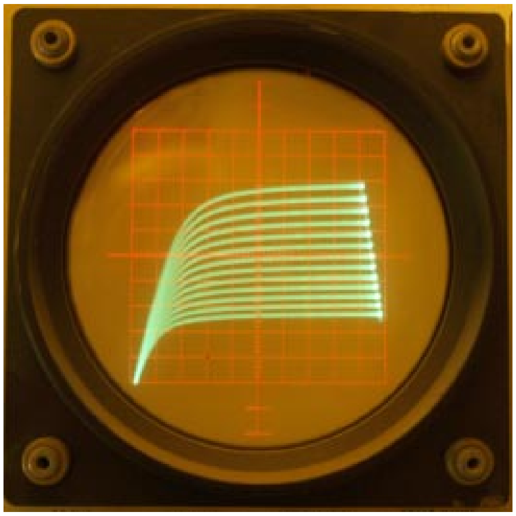

Fig. 1B - BF244B (100mV/step, vertical - 1mA/div, horizontal - 1V/div)

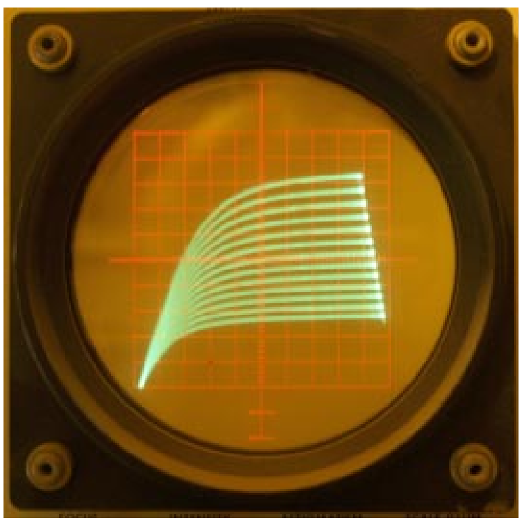

Fig. 1C - BF244C (200mV/step, vertical - 2mA/div, horizontal - 1V/div)

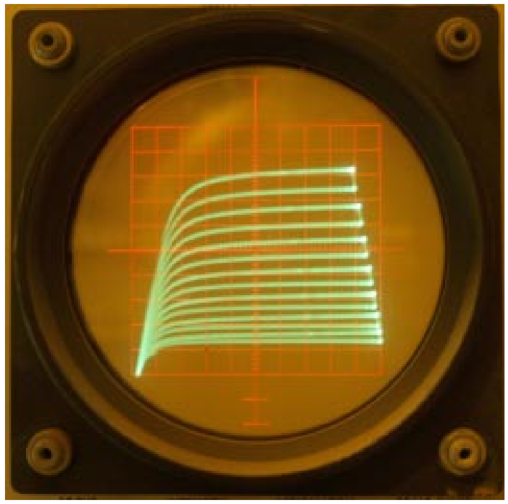

Fig. 1D - J309 (100mV/step, vertical - 2mA/div, horizontal - 1V/div)

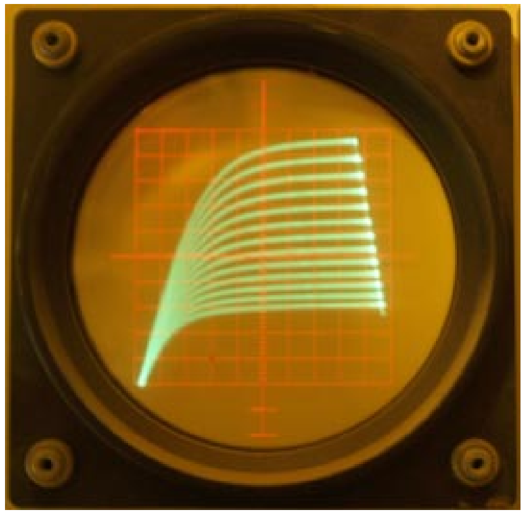

Fig. 1E - J310 (200mV/step, vertical - 5mA/div, horizontal - 1V/div)

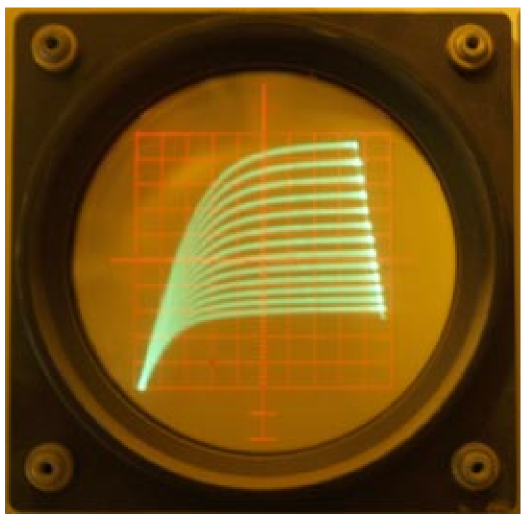

Fig. 1F - U310 (200mV/step, vertical - 5mA/div, horizontal - 1V/div)

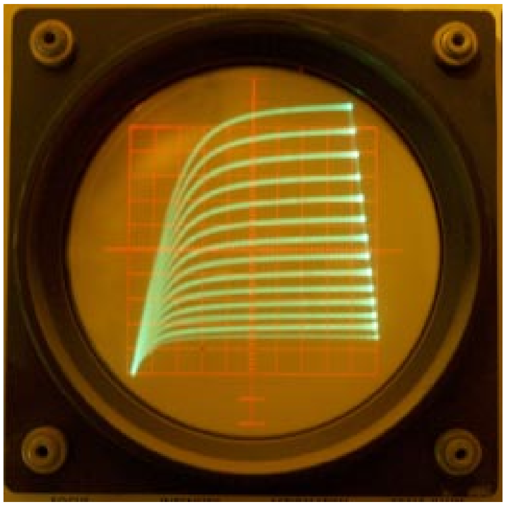

Fig. 1G - MPF102 (200mV/step, vertical - 1mA/div, horizontal - 1V/div)

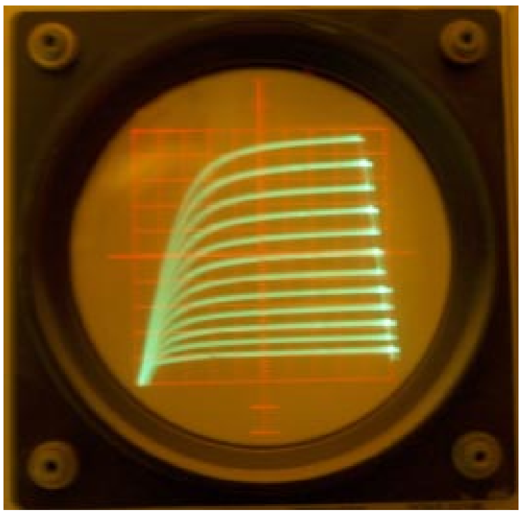

Fig. 1H - 2N3819 (200mV/step, vertical - 1mA/div, horizontal - 1V/div)

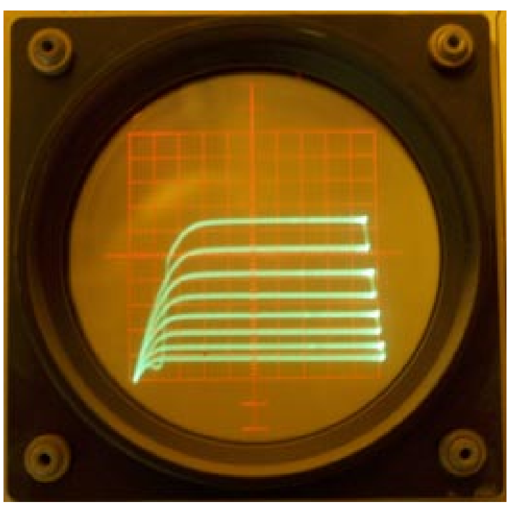

Fig. 1J - 2N4416 (200mV/step, vertical - 1mA/div, horizontal - 1V/div)

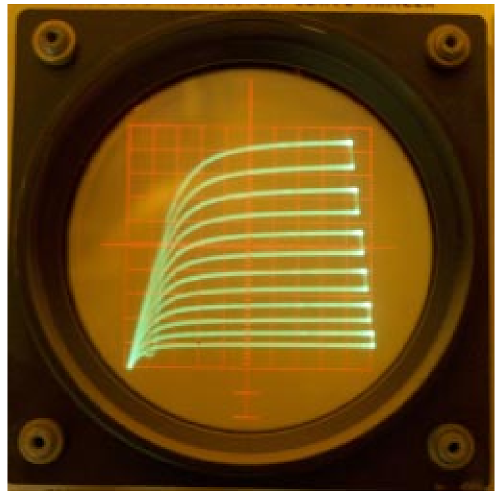

Fig. 1K - 2N5486 (200mV/step, vertical - 1mA/div, horizontal - 1V/div)

Fig. 1 - Curve families for various N-channel JFET transistors suitable for use in active antennas

not be said for the BF244C, which shows lower IMD performance. The suffixes for this family of devices differentiates them in terms of their gate-source voltage (V_{GS}) for a specific drain current.

The J308 (not shown in Fig. 1 or Table 1), J309, and J310 are a similar family devices in that they differ primarily by way of their gate-source voltage (V_{GS}). Regardless of this fact, the controversy as to the linearity characteristics of this family of devices, which includes the U310, will undoubtedly continue long after cockroaches become extinct. In observing the characteristic curves of Fig. 1E and Fig. 1F, the J310 and U310 (respectively) are virtually identical. For these two devices, there is a slight degree of g_m variation.

The J309 shows some degree of g_m uniformity between 5mA and 15mA of drain current, and the saturation and transition region

(*continued on page 7*)

Device	V_{DS}	P_D	gm	C_{iss}	C_{rss}	C_{oss}	NF	Price/Comments
BF244A/B/C	30V	350mW	5.6mS	3.0pF	0.7pF	0.9pF	1.5dB @ 100MHz 2.2dB @ 400MHz 2.8dB @ 500MHz	$0.13 (Mouser)
J309	25V	625mW	15mS	4.1pF	2.5pF	-----	3.0dB @ 450MHz	$0.17 (Mouser)
J310	25V	625mW	13mS	4.1pF	2.5pF	-----	3.0dB @ 450MHz	$0.17 (Mouser)
MPF102	25V	350mW	5.0mS	7.0pF	3.0pF	-----	-----	$0.11 (Mouser)
U310	25V	625mW	13mS	4.1pF	2.5pF	-----	3.0dB @ 450MHz	$0.25 (Mouser, SOT-23)
2N3819	25V	350mW	4.2mS	3.0pF	0.7pF	0.9pF	-----	$0.12 (Mouser)
2N4416	30V	300mW	6.0mS	2.2pF	0.7pF	1.0pF	2.0dB @ 100MHz 4.0dB @ 400MHz	$0.11 (Mouser, PN4416)
2N5486	25V	350mW	6.0mS	5.0pF	1.0pF	2.0pF	2.0dB @ 100MHz 4.0dB @ 400MHz	$0.12 (Mouser)

Table 1 - Static characteristics of N-channel JFET transistors suitable for active antenna applications

characteristics are better than those of the BF244 series, however the BF244 has a slight edge in terms of NF and overall g_m uniformity.

The MPF102, 2N3819, and 2N5486 share similar characteristics in all regards, and are virtually interchangeable.

The 2N4416 is a curious device. It is listed as being suitable for linear amplifier applications, but the variation of g_m seen in Fig. 1J reveals that it a lesser desireable device than are the BF244A/B. However, the virtual lack of variation in drain current beyond the transition region deserves some consideration. Despite the fact that the variation of g_m makes it unsuitable for linear amplifier service, it does make it very desireable as a square-law detector or as a transconductance mixer (RF and LO applied to the gate), which is a popular mixer topology for the front end of FM receivers.

P-Channel Devices

A series of six P-channel devices are described here, all of which are also currently available from Mouser at very reasonable prices. Fig. 2 displays a series of characteristic curves for each of these devices, while Table 2 lists some of the static characteristics as well as prices and sources for each.

The J174, J270, and J271 devices are very suitable for use with the J309 and J310 N-channel devices as complementary pairs, as I have demonstrated in an earlier publication on high-performance amplifiers for active short monopole antennas.

The 2N5460, 2N5461, and 2N5462 devices have lower g_m characteristics, however they have an obvious edge in terms of g_m uniformity and NF. They make excellent complements to the BF244A, BF244B, and BF244C, respectively, and are thus highly suitable for low-noise linear amplifiers at VHF frequencies

Synopsis

Just as with bipolar devices, when choosing JFET transistors for an active antenna and preamplifier design NF and IMD performance are most important and their impacts on the design need to be taken into consideration for the frequency range of the application. For frequencies at HF and below, NF becomes less important due to the increasing presence of terrestrial and galactic background noise as frequency decreases. At the same time, IMD performance becomes more important due to the crowding in the various broadcasting bands (BCB), especially that of MW frequencies as these high-power signals can generate harmonics in poorly designed amplifiers that will appear in the SWBC bands of the receiver.

Above HF frequencies, NF becomes increasingly important as the receiver NF will rise above the terrestrial and galactic background noise seen by the antenna. As this paper has been primarily focused on active antenna designs for HF frequencies and below, there has been little emphasis on this finer point of device selection.

The graphical presentation of device characteristics is the primary source for judging device linearity. From this form of data, the saturation region, transition region, and linear region characteristics of a device can be easily observed. Even so, only direct experience in equating these characteristics with amplifier performance will bring the designer to forming a basis for judgement.

Fig. 2 (following page) - Curve families for various P-channel JFET transistors suitable for use in active antennas

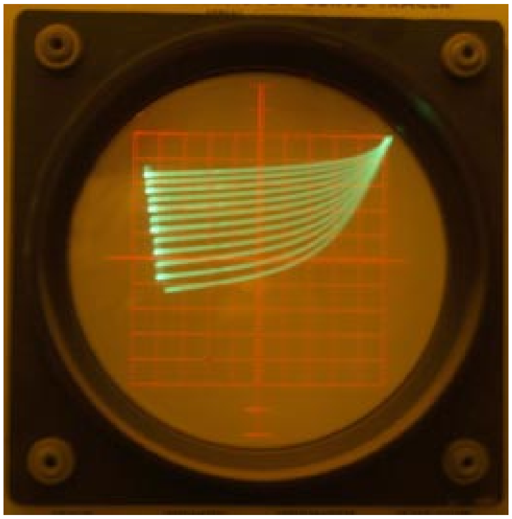

Fig. 2A - J174 (200mV/step,
vertical - 5mA/div, horizontal - 1V/div)

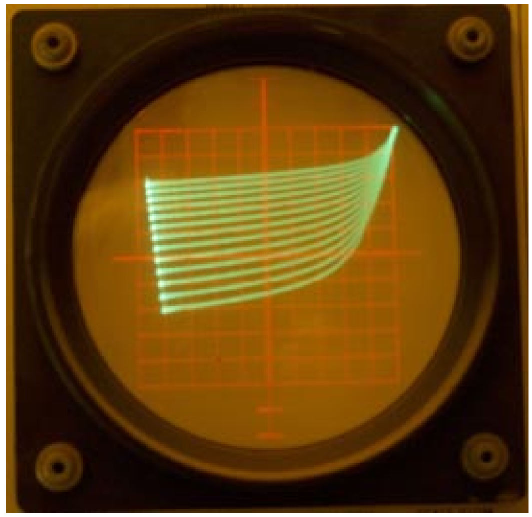

Fig. 2D - 2N5460 (100mV/step,
vertical - 0.5mA/div, horizontal - 1V/div)

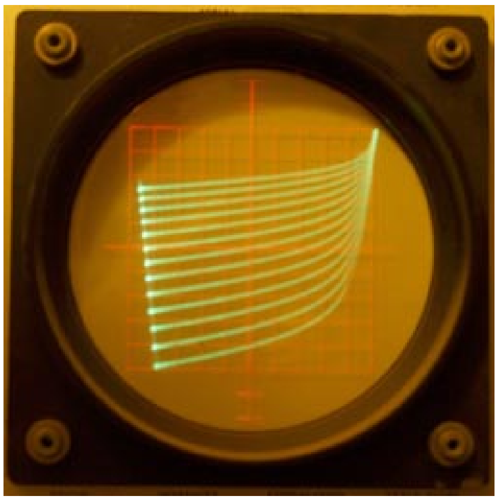

Fig. 2B - J270 (50mV/step,
vertical - 0.5mA/div, horizontal - 1V/div)

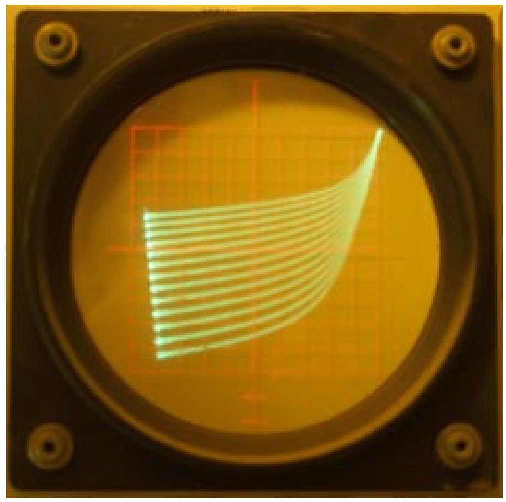

Fig. 2E - 2N5461 (100mV/step,
vertical - 0.5mA/div, horizontal - 1V/div)

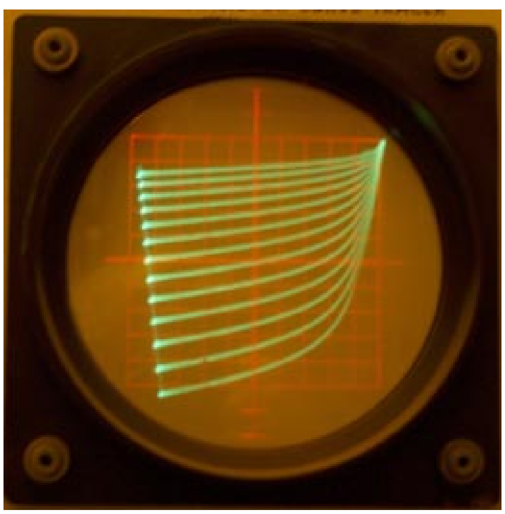

Fig. 2C - J271 (100mV/step,
vertical - 1mA/div, horizontal - 1V/div)

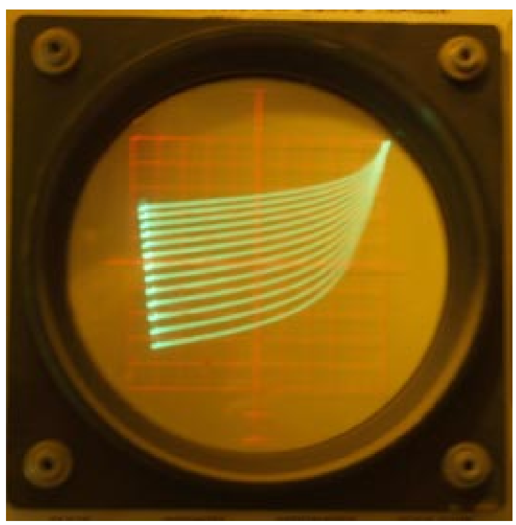

Fig. 2F - 2N5462 (100mV/step,
vertical - 0.5mA/div, horizontal - 1V/div)

Device	V_{DS}	P_D	gm	C_{iss}	C_{rss}	C_{oss}	NF	Price/Comments
J174	30V	350mW	6.0mS	8.0pF	3.0pF	-----	-----	$0.26 (Mouser)
J270	30V	350mW	10.5mS	20pF	4.0pF	-----	-----	$0.51 (Mouser)
J271	30V	350mW	13mS	20pF	4.0pF	-----	-----	$0.51 (Mouser)
2N5460	40V	350mW	2.5mS	6.0pF	1.5pF	-----	1.0dB	$0.15 (Mouser)
2N5461	40V	350mW	3.2mS	6.0pF	1.5pF	-----	1.0dB	$0.15 (Mouser)
2N5462	40V	350mW	4.0mS	6.0pF	1.5pF	-----	1.0dB	$0.15 (Mouser)

Table 2 - Static characteristics of P-channel JFET transistors suitable for active antenna applications